FAQ

1. What is the analytic element method?

2. Where can I get analytic element models?

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1. What is the analytic element method?

By Henk Haitjema, Indiana University: "The analytic element method was developed at the end of the seventies by Otto Strack at the University of Minnesota (Strack and Haitjema, 1981a). There are two books about the analytic element method, Groundwater Mechanics by O. D. L. Strack, Prentice Hall, 1989, contains detailed mathematical descriptions of the analytic elements and their numerical implementation. Analytic Element Modeling of Groundwater Flow by H. M. Haitjema, Academic Press, 1995, provides the basic theoretical framework for the analytic element method and focuses on its use. This new method avoids the discretization of a groundwater flow domain by grids or element networks. Instead, only the surface water features in the domain are discretized, broken up in sections, and entered into the model as input data. Each of these stream sections or lake sections are represented by closed form analytic solutions: the analytic elements. The comprehensive solution to a complex, regional groundwater flow problem is obtained by superposition of all, a few hundred, analytic elements in the model. Traditionally, superposition of analytic functions was considered to be limited to homogeneous aquifers of constant transmissivity. However, by formulating the groundwater flow problem in terms of appropriately chosen discharge potentials, rather than piezometric heads, the analytic element method becomes applicable to both confined and unconfined flow conditions, as well as to heterogeneous aquifers (Strack and Haitjema, 1981b). The analytic elements are chosen to best represent certain hydrologic features. For instance, stream sections and lake boundaries are represented by line sinks, small lakes or wetlands may be represented by areal sink distributions. Areal recharge is modeled by areal source distributions (areal sinks with a negative strength). Streams and lakes that are not fully connected to the aquifer are modeled by line sinks or area sinks with a bottom resistance. Discontinuities in aquifer thickness or hydraulic conductivity are modeled by use of line doublets (double layers). Specialized analytic elements may be used for special features, such as drains, cracks, slurry walls, etc. Locally three-dimensional solutions may be added, such as a partially penetrating well (Haitjema, 1985)."

References

1. Haitjema, H.M. (1985). Modeling three-dimensional flow in confined aquifers by superposition of both two- and three-dimensional analytic functions. Water Resour.Res., 21(10):1557-1556.
2. Haitjema, H.M. (1995). Analytic Element Modeling of Groundwater Flow. Academic Press, Inc.
3. Strack, O.D.L. & Haitjema, H.M. (1981a). Modeling double aquifer flow using a comprehensive potential and distributed singularities 1. Solution for homogeneous permeabilities. Water Resour.Res., 17(5):1535-1549.
4. Strack, O.D.L. & Haitjema, H.M. (1981b). Modeling double aquifer flow using a comprehensive and potential and distributed singularities 2. Solution for inhomogeneous permabilities. Water Resour.Res., 17(5):1551-1560.
5. Strack, O.D.L., Groundwater Mechanics, Prentice Hall, 1989.

SLIDE PRESENTATION

Bakker, Mark, and Stephen Kraemer, 2001. Groundwater modeling with analytic elements: cultivating understanding of groundwater systems, EPA/NERL/ERD Seminar, Athens, GA, March 8.

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2. Where can I get analytic element models?

PRESS RELEASES
2June2001

COMPUTATIONAL ENGINES	MODELING SYSTEMS
SLWL	WhAEM2000
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GFLOW-EPA	VisualBlueBird
3DFlow	Arcflow
PhreFlow	Winflow
Split	TWODAN
Tim	SLAEM, MLAEM/2, MLAEM

SLWL
Web: strackconsulting.com/home (comes with book Groundwater Mechanics)
License: Free

“SLWL is a Fortran code for flow in single layer homogenous aquifers including functions for wells, line sinks, ponds, uniform flow, and rainfall recharge functions.”

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ModAEM
Web: modaem.sourceforge.net
License: Open source GPL

"A high performance, open source, analytic element code, written in object-based Fortran, designed for interfacing with other models or GUIs.
ModAEM is highly modular in design, parallelizable, and a production code. ModEAM is the solution engine for the EPA modeling system WhAEM2000 version 1 (http://www.epa.gov/ceampubl/gwater/whaem/index.htm)."

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GFLOW-EPA
Web download: ftp://ftp.epa.gov/sandyrun/WhAEM_Development/Solver/
License: Open source, artistic license (contact Kraemer for details).

"An open source version of the GFLOW solution engine by Henk Haitjema that is part of the EPA modeling system WhAEM2000 version 2 (http://www.epa.gov/ceampubl/gwater/whaemb/index.htm)."

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3DFlow
Web download: groundwater.ce.ksu.edu
License: Public domain

"3DFlow is a public domain, interactive computer tool that models and visualizes 3D groundwater flow. This tool simulates steady flow to horizontal wells, partially penetrating wells, and fully penetrating wells in a regional field of uniform flow. Aquifer features may be located in a horizontal aquifer bounded by two planes, in a semi-infinite aquifer bounded by one horizontal plane, or in an aquifer that is infinite in extent. 3DFlow provides an interactive learning environment with pull-down menus and projection of a 3D view region on the screen.

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Split
Web download: www.groundwater.buffalo.edu/software/software.html
License: Free

"Split is a program for analytic modeling of single-layer groundwater flow in heterogeneous aquifers. Split includes particle tracking, capture-zone delineation, and parameter estimation. Split supports modeling of inhomogeneities bounded by polygons, spatially variable recharge, rivers and lakes with bed resistance, discharge- and head- specified boundaries, and many other features. The only input is hydrogeologic features. The user is not required to make decisions that affect the numerics of the underlying computational engine."

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PhreFlow
Web download: www.groundwater.buffalo.edu/software/software.html
License: Free

"PhreFlow models 3D transient flow and advective transport in a domain bounded by an impermeable base, a phreatic surface with recharge, and head specified lateral boundaries. The domain may contain an arbitrary number of wells of any orientation and inhomogeneities shaped as rotational ellipsoids of arbitrary conductivity. The well discharges and recharge can vary with time. PhreFlow uses a combination of the analytic element method to account for spatial distribution of heads and discharges and a finite difference method to account for transient conditions. PhreFlow outputs include heads, particle pathlines and capture zones. The programs Split and PhreFlow have also been used to investigate macroscopic dispersion. Research versions of these programs allow for implementation of as many as 100,000 circular inhomogeneities in 2D (Split) and 10,000 inhomogeneities shaped as rotational ellipsoids in 3D (PhreFlow) with analytic accuracy. The programs, including examples, manuals, references and movies depicting the dispersion process, may be downloaded from the web site above."

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Tim
Web: www.engr.uga.edu/~mbakker/tim.html
License: Open Source GPL

"The main objective of the Tim project is to develop free, open source, object-oriented software for modeling of ground-water flow using analytic elements. Two programs have been developed: a single version TIMSL, and a multilayer version TIMML. The programs have a full object-oriented design that was developed with the input from a large group of analytic element developers. The Tim codes are open-source computer programs, which means that the source code is freely available and the user can make any modifications they like. Furthermore, when users develop features that may be useful for other users, they are supposed to give their developments back to the Tim project so that they can be included in the official release. The object oriented design of the Tim codes are basic, but flexible, so it is easy to learn how the program is structured and to make changes or additions. The Tim codes are written in Python. Python is an interpreted, interactive, object-oriented programming language. Python is powerful yet the syntax is surprisingly clear (it is easy to learn). Python runs on virtually any operating system, including Unix, Linux, Mac, and Windows. Python is open source, so you can download it for free from the web (www.python.org)."

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MODELING SYSTEMS

WhAEM2000
Web download: http://www.epa.gov/athens/software/whaem/index.html
License: Public domain

The U.S. EPA's Wellhead Analytic Element Model, WhAEM2000 for Windows (95/98/NT), is a ground water

geohydrology computer program. WhAEM2000 is a public domain, ground-water flow model designed to facilitate capture zone delineation and protection area mapping in support of the State's Wellhead Protection Programs (WHPP) and Source Water Assessment Planning (SWAP) for public water supplies in the United States. WhAEM2000 provides an interactive computer environment for design of protection areas based on radius methods, well in uniform flow solutions, and geohydrologic modeling methods. Protection areas are designed and overlaid upon US Geological Survey Digital Line Graph (DLG) or other electronic base maps. Base maps for a project can be selected from a graphical index map for the State. Geohydrologic modeling for steady pumping wells, including the influence of hydrological boundaries, such as rivers, recharge, and no-flow contacts, is accomplished using the analytic element method.

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GFLOW2000
Web download: www.haitjema.com
License: Proprietary

“GFLOW 2000 is a highly efficient stepwise groundwater flow modeling system developed by Haitjema Software, a subdivision of Haitjema Consulting, Inc. GFLOW 2000 is a Windows 95/98/NT program based on the analytic element method. It models steady state flow in a single heterogeneous aquifer using the Dupuit-Forchheimer assumption. While GFLOW 2000 supports some local transient and three-dimensional flow modeling, it is particularly suitable for modeling regional horizontal flow. To facilitate detailed local flow modeling, GFLOW 2000 supports a MODFLOW-extract option to automatically generate MODFLOW files in a user defined area with aquifer properties and boundary conditions provided by the GFLOW analytic element model. GFLOW 2000 also supports conjunctive surface water and groundwater modeling using stream networks with calculated baseflow. “

“For more information on using the analytic element method for groundwater flow modeling see the textbook "Analytic Element Modeling of Groundwater Flow" by Henk Haitjema, Academic Press, 1995. See also Amazon.com.”

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VisualBlueBird
Web download: www.groundwater.buffalo.edu/software/software.html
License: Free

“A Visual Basic Windows GUI that creates input files for the public domain AEM code SPLIT.”

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ArcFlow
Web download: http://www.groundwater.buffalo.edu/software/split/ARCFLOW_.PDF
License: Open Source free software, requires Arcview 3

"ArcFlow is an ArcView extension that seamlessly connects the geographic modeling information to the SPLIT groundwater flow model. ArcFlow takes point, line, and polygon features, generated by the modeler in ArcView, and creates the Split input file; then uses dialog boxes for hydrogeologic and model input. Geographic information is read directly from active ArcView themes. Split is launched from ArcFlow and new themes with the model output (e.g., head contours, capture zones) are brought back into the ArcView project. Relevant GIS coverages are immediately available to the modeler for the construction of the model elements and for comparison with results. For example, ArcFlow automatically provides elevation of streams and rivers through a query of, for example, a digital elevation model. ArcFlow shows stream gains, losses and discharges, predicted by Split. Existing ArcView extensions and scripts can be included in the modeling process. New scripts and extensions can be created. Extensions have been created to manage image files, generate geologic cross-sections, and access well data bases. The result is an ArcView-based modeling system with an embedded groundwater model."

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WINFLOW
Web download: www.scisoftware.com/products/winflow_prices/winflow_prices.html
License: Proprietary

"WinFlow is a powerful yet easy-to-use groundwater flow model. WinFlow is similar to Geraghty & Miller's popular QuickFlow model which was developed by one of the authors of QuickFlow. The most notable improvement over QuickFlow is compatibility with Microsoft Windows V3.1/95/NT. WinFlow is a true Windows program incorporating a multiple document interface (MDI). WinFlow is an interactive analytical model that simulates two-dimensional steady-state and transient groundwater flow. The steady-state module in WinFlow simulates groundwater flow in a horizontal plane using analytical functions developed by Strack (1989). The transient module uses equations developed by Theis (1935) and by Hantush and Jacob (1955) for confined and leaky aquifers, respectively. Each module uses the principle of

superposition to evaluate the effects from multiple analytical functions (wells, etc.) in a uniform regional flow field."

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TWODAN
Web download: www.fittsgeosolutions.com
License: Proprietary

"TWODAN stands for TWO-Dimensional ANalytic groundwater flow model. Version 5.0 combines advanced analytic elements with an excellent user interface. It is a 32-bit Windows application with a familiar and simple user interface. TWODAN's capabilities, interface quality, and price make it a great value for 2-D flow modeling. It is a good tool for many remediation design, capture zone analysis, and regional modeling problems."

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SLAEM, MLAEM/2, MLAEM
Web download: strackconsulting.com/home
License: Proprietary

"The AEM family of computer programs, presently SLAEM, MLAEM/2, and MLAEM, are based on the Analytic Element Method, developed by Dr. O.D.L Strack. For a description of the Analytic Element Method, see Groundwater Mechanics by O.D.L Strack (Prentice-Hall, 1989). The computer programs are intended for modeling regional groundwater flow in systems of confined, unconfined, and leaky aquifers. SLAEM (Single Layer Analytic Element Model) is the single-layer version of the program, MLAEM/2 (Mulit Layer Analytic Element Model) can access 2 layers, while the number of layers supported by MLAEM is limited only by hardware. All programs run under UNIX (on Sun computers) and under Microsoft Windows® 95 and NT®. The programs are native windows applications and are accessed via a modern and flexible Graphical User Interface (GUI), as well as via a command-line interface. The atter capability makes it easy to drive the program from other programs like Arc-View, Arc-Info, and PEST. The programs create files from data entered graphically via the GUI; these files can be read in later. The programs read DXF-files and produce BNA files that may be read by other programs, such as SURFER."

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